Appendix K

Literature Review of Revetments

ANNOTATED BIBLIOGRAPHY OF IMPACTS OF RIPRAP HABITATS ON FISH POPULATIONS

Written by: U.S. Army Corps of Engineers, Seattle District.
March 13, 1997; Updated June 1, 2001

PACIFIC NORTHWEST

	TITLE	AUTHORS	SUMMARY
1	**Effects of Riprap Bank Reinforcement on Juvenile Salmonids in Four Western Washington Streams.**	Li and Shrek. 1984 NOTES: • Lower Deschutes River data is similar to Skagit River conditions. The riprap conditions evaluated apply to larger streams. Decker Creek is the second most similar. • No coho were found at the Lower Deschutes test section.	• Examined summer and fall salmonid populations. • Abundance of coho and trout young-of-year (YOY) declined in newly riprapped sections of larger streams while steelhead and cutthroat populations increased. • Negative short-term effects of construction increased with severity of habitat alteration, and decreased with an increase in stream size, and increasing fish size. • Previous research shows: lost production under certain conditions in streams having discharges of less than 10 ft^3/s. Large decreases in salmonid production after channelization (but not through the use of riprap) on Big Beef Ck. • Other studies show a potential to increase production through additions of habitat complexity, but little research has been done to show effects of removing habitat complexity. • Results show population increases for all salmonids (except trout) over time in all larger-stream construction sites. However, the increases were smaller than those observed at control sites, indicating greater preference for habitat conditions found in control sections.

	TITLE	AUTHORS	SUMMARY
2	**Channelization and Livestock Impacts on Salmonid Habitat and Biomass in Western Washington**	Chapman and Knudsen. 1980 NOTES: • Channelization impacts winter habitat most. • Some test sites had more biomass in the summer than observed at control sites. The cause was determined to be less vegetation and more light at test sites.	• Studied conditions in streams of less than 0.3 m/sec velocity. • Characterized impact by exposure of raw soil, in-water placement of riprap, time since disturbance, and general appearance. • During summer sampling, coho were least affected by riprap, and cutthroat (largest) were the most affected. • Found no potential predator/prey correlation for cutthroat and coho. • 25 percent more fish in test in summer; 95 percent fewer fish in winter. • Neither the test or control reaches held many coho salmon during the winter months because the biomass was at only two percent of that recorded in the summer. • Light availability may be an important limiting factor for salmonid biomass in the summer in many streams. • Removal of the canopy and streamside vegetation over substantial reaches can cause low salmonid biomasses.
3	**Comparison of Habitats Near Spur Dikes, Continuous Revetments, and Natural Banks for Larval, Juvenile and Adult Fishes of the Willamette River.**	Li and Shreck. 1984 NOTES: • This study focused on all species of fish including cyprinids, catastomids, centrarchids, salmonids, and cottids. Cooler water was found to be detrimental when considering all species inclusively. • The study determined that groins provide better habitat than continuous revetments. There is not enough information on salmonids to determine their preferences, although other references suggest they prefer roughened habitats.	• The diversity and density of larval and juvenile fishes at spur dikes (groins) were intermediate between natural banks and continuous revetments. Spur dikes were found to accumulate woody debris better. • Two factors were consistent among the species observed: juvenile fishes avoided velocities greater than 11 cm/sec, and they were found at depths no greater than 30 cm. • Fish composition between natural and riprap banks differed. High densities of a smaller number of species were found in revetted habitats. Mostly those that fed on bottom-dwelling invertebrates and green algae/diatoms and small fishes able to use the interstices as cover.

	TITLE	AUTHORS	SUMMARY
			• Larval fishes were observed in the interstices of the riprap banks near shore but not sampled. • Large-scale sucker juveniles were supported best by natural banks, spur dikes and lastly, continuous revetments. • Juvenile sculpins tended to avoid riprap with only a few obsereved in its proximity. • Bass, bluegill, catfish, and crappie were not caught in riprapped sections.
4	**Effects of Stream Channelization on the Salmonid Habitat and Populations of Lower Big Beef Creek**	Cederholm and Koski. 1977 NOTE: • This report describes wide-spread damage to a river system due to bulldozing a new channel. It includes little discussion on streambank problems.	• Historically, Big Beef Creek was channelized to reduce flooding. • Channelization resulted in an increase in sediment contribution, streambed scour and a decrease in habitat characteristics. • Coho populations recovered faster than steelhead in the four years following channelization. • Chum salmon redds declined and shifted upstream to compensate for channelized sections. • Four years following channelization, bank cover returned to levels 50 percent prior to channelization (Alders grew to 2 meters). • There is evidence that coho may avoid dense cover in summer, and prefer open glides while steelhead prefer dense shade. • The report recommends using riprap as an alternative to channelization. • Large decreases in salmonid production were observed after channelization (not using riprap) on Big Beef Creek.
5	**The Short Term Physical and Biological Effects of Stream Channelization at Big Beef Creek Kitsap County, Washington.**	Cedarholm. 1972 NOTES: • The stated reason for channelizing was to improve salmon and trout rearing and spawning habitat, and for flood control.	• A literature review of studies that looked at alterations of the physical habitat by channelization revealed that: • the effects of man-made stream-channel alterations on game-fish (trout) production in 13 Montana streams produced only one-fifth the number of game fish as did unaltered section os the stream.

TITLE	AUTHORS	SUMMARY
	• Channel was bulldozed and cleared. • Pools and cover changes were measured. • Traditional chum spawning areas within the project area were found to move upstream and outside the channelization.	• Survey of 45 different Idaho streams that had undergone stream alterations found that undisturbed stream channels produced from 1.5 to 112 times more pounds of game fish than disturbed channels. On average, undisturbed sections contained eight times greater poundage of game fish. • Channelization of Big Spring Creek in Montana resulted in the complete destruction of trout stream habitat. After channelization, the pools, riffles, bank vegetation, invertebrates and other essentials were lost. • Various construction activities affecting rivers and streams, particularly direct modification of natural meanders through straightening and deepening, causes substantial losses of productivity compared to the original natural stream configurations. • The chum salmon may recognize the lack of hiding cover in channelized sections, resulting in their movement to more suitable areas upstream. • Accelerated streambank erosion and streambed degradation was observed within the channelized area. • Both coho and steelhead prefer habitat associated with pools. Pools with permanent hiding cover result in the greatest overwintering salmonid populations. Their abundance in pools presumably represents an integration of all the factors (besides space) that regulate their health and numbers, such as food production in the riffle areas. • Pool densities were low compared to conditions before channelization. • Two years following stream channelization, the number of juvenile coho per square meter increased to about 150 percent the density found before channelization (densities were measured in pools only).

	TITLE	AUTHORS	SUMMARY
			• Steelhead recovery was slow, partially because of reduced streambank cover. • Removing streambank cover reduces the number and weight of trout. Rainbow trout were more active in Shagehen Creek in relation to overhead cover. Alterations that increased hiding places increased the survival-rate percentage of brook trout fingerlings. • Increases in overwintering survival of brook trout is believed due to physical improvement in space-refuge factors (cover, depth, pool area). • Emigration of rainbow and chinook was reduced when there was substantial amounts of cover provided by large rubble.
6	**Pilot Study of the Physical Conditions of Fisheries Environments in River Basins on the Olympic Peninsula**	Orsborn. 1990 NOTE: • Interstitial spaces were used by rainbow, cutthroat and chinook.	• Newly emerged fry were found to move to shallow margins. • Migration to deeper and faster water occured as fishes grew. • All species seek cover habitat when water temperatures decrease in the fall and winter. • Overwintering habitat is the limiting factor in many drainages. Interstitial spaces are used by juvenile rainbow, cutthroat and chinook. Side channels are used by coho.
7	**Distribution of Fish and Stream Habitats and Influences of Watershed Conditions, Beckler River, Washington**	Wissmar and Beer. 1994 NOTE: • LWD contributes to habitat complexity and potential carrying capacity.	• During the 1980s, concern about declining coho and chinook stocks led to cooperative efforts to initiate stream-channel, bank-stabilization and habitat-improvement projects in the Beckler River basin. Monitoring of populations has been too infrequent to determine the success of these projects. • Recruitment of large woody debris occurs as channels shift and streambanks erode during periods of high discharge. • The presence of large woody debris increases the surface area and roughness of the streambank and channel, contributing to habitat complexity and potential carrying capacity.

	TITLE	AUTHORS	SUMMARY
			• Degradation of stream habitats by channel erosion and removal of large woody debris is evident in the greatly reduced habitat diversity and potential capacities to support fish. • The stream network needs to connect habitats required for: 1) various fish life cycles, 2) refuge from disturbances, 3) source areas that provide population for colonizing disturbed and restored habitats.
8	**Rock Size Affects Juvenile Salmonid Use of Streambank Riprap.**	Lister et al. 1995	• Assessment of habitat alteration in two southern British Columbia streams. The Thompson River wetted channel width is 100 m to 200 m wide with a mean annual discharge of 775 m^3/s. • Along the Thompson River, large riprap supported higher chinook and steelhead densities than small riprap and cobble-boulder banks during summer and winter. • Densities were greater along large riprap banks than small riprap banks, but wild coho exhibited no preference. • Suitable banks for juvenile salmonids were relatively steep, contained large rock and were constructed in a way that maximized roughness. • Study sites were situated for observing rearing and overwintering juvenile chinook salmon and rainbow steelhead trout. • It was assumed that salmonid juveniles at the study sites were rearing, not actively migrating. • It is assumed that visual checks provided valid estimates of relative bank-material size. Noted in previous winter studies juvenile salmonids were hiding within the substrate during the day. • Juvenile chinook, coho and steelhead parr were observed at higher densities at boulder-placement sites than reference sites without boulders.

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			• Drifting insects are the primary food source for salmonids. Drift at a given location was positively related to water velocity. Scientists have observed that juvenile chinook salmon and steelhead trout occupied stations that allowed them to hold position in low- or near-zero velocity, usually near the stream bottom but adjacent to high-velocity flow. • Large riprap usually supported higher juvenile salmonid densities than banks composed of either natural cobble-boulder material or small riprap. • Fish distribution was clumped – 72 percent of the population was found within only 17 percent of the study site. • Additions of large boulders increased stream-habitat desirability for juvenile coho salmon and steelhead trout. • Interstices within the riprap blanket provided refuge for fish. The preference of Thompson River chinook and steelhead for large riprap in winter reflects their tendency to seek cover within a boulder or rubble substrate for overwintering. • It was recommended that riprap embankments intended to provide habitat for juvenile salmonids be constructed of coarser material than typically specified through common design criteria. Also, the practice of providing a hydraulically efficient surface is contrary to habitat requirements.
9	**FY 1995 Skagit River Chinook Restoration Research**	Hayman et al. 1996 NOTES: • Backwater and natural banks are more productive as fish habitat than riprap. Setback levees in lower rivers could be very productive. • This report does not include lower Skagit habitats.	• Investigation compared backwaters, natural banks, hydromodified banks (riprap), and bar habitat. • 0+ year chinook production (fish/m^2) was 1.78 (backwater), 0.97 (natural), 0.348 (riprap), and 0.44 (bar habitat). • Yearling chinook did not rear in any of the sampled areas.

	TITLE	AUTHORS	SUMMARY
			• Three types of fish life cycles were observed: 1) emergent fry migrating to ocean, 2) emergent fry rearing in estuary before ocean, 3) fingerling migrants (90-day) that emerge and reside in freshwater before migrating to the ocean. • Chinook use of hydromodified banks (riprap) averaged four times less than natural banks.
10	**Seasonal Fish Densities Near River Banks Stabilization Methods, First Year Report for the Flood Technical Assistance Project.**	Peters et al. 1998 U.S. Fish and Wildlife Service, North Pacific Coast Ecoregion Western Washington Office Aquatic Resources Division, Lacey, Washington.	• Study evaluated seasonal salmonid densities at five different types of bank-stabilization projects (riprap, riprap with large woody debris (LWD), rock deflectors, rock deflectors with LWD, and LWD exclusively) relative to natural control areas near the stabilized site. • Sites stabilized using large woody debris had consistently greater salmonid densities than their associated control areas. • Juvenile chinook and total juvenile salmonids densities during the spring were significantly lower at riprap-stabilized sites than natural control areas. • Coho fry densities during the spring were significantly lower at combination stabilized sites than at natural control areas. • Salmonid fry, total juvenile salmonids and total fish densities during the winter were significantly greater at sites stabilized using LWD than at natural control areas. • 1+ age trout densites during the spring were greater at sites using a combination of bank-stabilization techniques than at natural control areas but were lower at rock-deflector-stabilized sites. • 1+ age trout densities during the summer were significantly less at riprap-stabilized sites than at natural control areas. • 2+ age trout densities during the spring were significantly lower at deflectors than at natural control areas.

	TITLE	AUTHORS	SUMMARY
			• 0-age trout densities during the spring were greater at rock-deflector sites than at natural control areas. • LWD incorporated into riprap and rock deflectors did not improve rearing conditions for juvenile salmonids. The authors believe that this was the result of poorly placed LWD. The woody material formed only sparse cover for salmonids, since single logs or trimmed rootwads were used. The performance of large woody debris as mitigation in riprap and rock deflector projects may have been improved if the debris formed complex cover, which could have provided juvenile salmonids refuge from predators.
11	**Habitat Complexity, Salmonid Use, and Predation of Salmonids at the Bioengineered Revetment at the Maplewood Golf Course on the Cedar River Washington.**	Missildine et al. 2001	• The study examined the influence of modifying a riprap bank-stabilization project into a rock-deflector, large woody debris (LWD), and bioengineered (combination) bank-stabilization project on habitat complexity and fish densities from January to mid-June. • Habitat complexity, in the form of secondary habitats and cover, increased at the new combination project compared to the old riprap project. • Mean water velocities at the new combination project were more favorable for juvenile salmonid rearing. • Relative densities of salmonid parr and cottids were consistently greater at the new combination revetment than at a naturally stable bank that served as a control site. • Juvenile chinook salmon and total salmonid relative densities were less at the new revetment compared to the control area during January through March, though greater from April through June.

	TITLE	AUTHORS	SUMMARY
			• Relative densities of chinook salmon, salmonid parr, total salmonids, and cottids were greater at the new combination project than the old riprap project. • Predation on salmonids was relatively low at the combination project and the control area.
12	**Juvenile Salmonid Use of Natural and Hydromodified Stream Bank Habitat in the Mainstem Skagit River, Northwest Washington.**	Beamer and Henderson. 1998 Skagit System Cooperative Report prepared for U.S. Army Corps of Engineers, Seattle District, Environmental Resources Section. La Conner, Washington.	• Study compared juvenile salmonid use at natural and hydromodified (rip rap) bank types in the mainstem Skagit River. • Natural banks had a greater accumulation of wood versus hydromodified banks. • Wood cover was found to increase over time after hydromodification. • Juvenile chinook and coho were more abundant in areas with greater wood cover. • Juvenile rainbow showed preference for riprap (large-size rock). • Fish abundance was greater in rootwad cover versus single logs for all species except sub-yearling chum. • Sub-yearling chum prefer aquatic plants and cobble. • The findings suggest that the use of natural cover types along with bank protection may mitigate some site-level (but not reach-level) impacts of hydromodification.

CALIFORNIA

	TITLE	AUTHORS	SUMMARY
1	**Woody Vegetation and Riprap Stability Along the Sacramento River Mile 84.5 -119.**	Shields. 1991 NOTE: • This document examined the effects of vegetation on hydromodified streambanks, including the reduction of channel conveyance, impairment of revetment visibility for inspection, hindrance of flood-fighting activities, adverse effects on revetment durability from local scour by growth and uprooting of trees, and piping through levees caused by roots (Gray et al, 1991)	• Since revetment vegetation occurs along riparian corridors, its habitat value per unit area is greater than similar vegetation away from waterways. • Aerial photography showed that about 11 percent of the revetted segments supported woody vegetation types 2 (woody vegetation 4-12 ft high) or 3 (woody vegetation greater than 12 ft high) prior to the flood, but only nine percent after the flood. • Relative to aerial photos, state inspection records under-reported revetment vegetation by about 80 percent, indicating only two or three percent of the revetted bank line was vegetated before and after the 1986 flood, respectively. • Review of files revealed five instances of revetment damage attributed to the 1986 flood in the study reach. None of the five sites supported woody vegetation before or after the flood. • Damage rate for vegetated segments was roughly twice as high as for unvegetated segments, this was due to the fact that vegetated revetments were generally older. In fact, when revetments of similar age, material, and location were compared, vegetated revetments were less damaged.
2	**Juvenile Salmon Study Butte Basin Reach: Sacramento River Bank Protection Project.**	U.S. Fish and Wildlife Service. 1992	• The objective of this study was to determine the relative abundance of juvenile chinook salmon relative to various rock revetment arangements. • Monitoring occurred over three years. • The study looked at natural banks, rock fish groins and standard revetments. • Rock revetments alone had the lowest average habitat value and lowest value two out of the three years.

	TITLE	AUTHORS	SUMMARY
			• Rock groins had the greatest incremental benefits when comparing habitat improvement against cost. • Present bank-stabilization practices and riprapping destroys most, if not all, unique values of shaded riverine aquatic cover. • Example of the impacts of riprap is the transformation of irregularly shaped riverbanks to ones that are straightened and covered with a uniform, smooth layer of quarry rock. • Results of the study indicate that the experimental mitigation measures were able to recover some habitat values lost from revetments. Though none appeared to provide full replacement of habitat value based on the salmon utilization measurements. • Avoidance mitigation such as set-back levees and other approaches are recommended.
3	**Study of the Effects of Riprap on Chinook Salmon in The Sacremento River, California**	U.S. Fish and Wildlife Service 1988 NOTE: • This study was an effort to statistically determine density-dependent effects of riprap revetments on Chinook salmon.	• Study found that greater numbers of juvenile chinook salmon can be captured along cut banks than along riprap in the Sacramento River. The significance of these observations depends upon whether or not density-dependent mortality is important for young salmon that depend on the limited amounts of food and space available in the river. • Study recommended that efforts to evaluate alternatives to standard riprap, such as different slope configurations and the use of larger rocks should be continued. • A long-term effect, perhaps lasting for centuries, could result from cessation of bank erosion because it eliminates most spawning-gravel recruitment. • If loss of habitat is the only direct result of riprap installation (quantity change but not quality change) where there is surplus rearing habitat, then the riprap will likely have no effect on the production of salmon.

	TITLE	AUTHORS	SUMMARY
			• Where rearing habitat is limited, survival of juvenile salmon may decline where riprap has been installed. Fish grow faster and avoid predators more effectively in natural, unaltered habitat. • Satisfactory approaches are not available to assess separately the effect of a loss in quality of habitat and of a loss in quantity of habitat. Approaches are not available because knowledge of the movements and distribution of young salmon is poorly defined and capture of a large proportion of the fish in a reach of stream is not practical. • Juvenile salmon are more accepting of riprap when large rock is used; however, this material may also attract predator fishes.
4	**Sacramento River and Tributaries Bank Protection and Erosion Control Investigation. Evaluation of Impacts to Fisheries.**	State of California Department of Fish and Game. 1983 NOTE: • Major diet components were not significantly different between test and control area	• The study noted the presence of three insect families that comprised the majority of the chinook diet including: chironomid, mayflies, and aphids. No statistical differences in the abundance of these insects were found between cut bank and riprap areas. • Average of only one-third the number of chinook in riprap vs. control areas. It was believed that differences relate to the increase in the zone of turbulent flow when large rock is present. • The study found a higher diversity of species present in riprapped areas than in the control areas, which is attributed to the large size of rock used. • Though steelhead trout were not a focus of this study, they were observed in the study area. There appears to be no significant difference in steelhead presence between riprap and natural habitat areas. • The majority of salmon fry migrate during darkness. Most downstream migration and emergence from gravel occurred at night with less than five percent of movement occuring during daylight hours.

	TITLE	AUTHORS	SUMMARY
			• It was suggested that the age of the riprap treatment has an effect on fish habitat preference (no evidence was mentioned to support this hypothesis). General observations indicate that low-velocity areas with considerable cover tend to have higher daytime salmon densities than the type of habitat typical of cut banks. Riprap effects probably do not extend all the way to mid-river. • Project impacts were believed to have caused a six-percent reduction in the abundance of adult spawners (this was, however, a near-worst-case estimate). • Sloping banks to provide shallow-water habitat at greater flow ranges may reduce the losses of fish .
5	**Biological Data Report Regarding Sacramento River Bank Protection Project Impacts on Winter-Run Chinook Salmon. Second and third Phases.**	ECOS, Inc. 1991 NOTES: • This report examined riprap size/type and its potential effects on salmonid use. • From historic levels only two to three percent of of the natural, woody, riparian vegetation remains along the Sacramento River. It is currently confined to an approximately 30 foot width. • Potentially adverse impacts resulting from the second-phase of the bank-protection project on habitat components were identified, although the extent of those impacts are difficult to quantify. Individual, incremental impacts are possibly minor.	• Since 1972, there has been a 22 to 26 percent reduction of river-edge riparian habitat. Most of this reduction is attributed to bank-stabilization projects. • Chinook salmon production is affected by riparian loss.The loss of a riparian buffer has caused changes in water temperature, reduced instream-cover and reduced habitat diversity. • The most significant, intermediate impacts to fishery resources occurs at bank-protection projects that involve removal of near-shore riparian vegetation, grading of the bank slope and placement of rock revetment over the graded slope. • The principal causes for low use of revetted areas by chinook juveniles are believed to be elevated velocity levels along riprap substrate and a reduction of large, instream cover habitat. Drift densities of invertebrate prey species was not found to be significantly different. • Data from other regions indicate that the impacts of riprap are greatest on fish health during the fry stage of development when their tolerance of depth and velocity extremes is narrower. • Chinook fry are less likely to be displaced by stream flows into downstream riprapped areas than are other salmonid types that emerge during winter or spring.

TITLE	AUTHORS	SUMMARY
		• Riprap affects smolts most during periods when fish are stationary and feeding (typically during daylight hours). • Juvenile chinook are commonly found associated with instream cover, which shelters juveniles from predators and severe environmental conditions and provides efficient feeding stations. An explanation for their presence at sites without instream cover was not provided by this work. • Low-hanging riparian vegetation, undercut banks and submerged woody debris are important habitat components for rearing juvenile salmonids as protection from avian and terrestrial predators and as sources of shade. • Little is known concerning the importance of shade to juvenile chinook salmon, although it is significant during periods of elevated water temperatures. • Construction-related increases in water turbidity were local and temporary. Juvenile salmon avoid turbid water as will adult salmon. Decreased production of fish-food organisms caused by turbidity was not found to be significant by this study. • Water velocities in proximity to large, angular rock may negate its positive characteristics and partly explain the low use of riprap habitat by juvenile chinook salmon. • Replacement of woody debris or natural substrate cover with quarry rock results in a reduction of habitat quality. • It was found that higher numbers of juvenile chinook salmon congregate around cut bank rock revetment sites where both gravel and fish groins have been added, than found at nearby natural areas. • Juvenile chinook abundance was observed to be higher at rock revetted areas with fish groins than at standard rock areas, although the extent of the mitigative value of groins has not been quantified.

TROUT HABITAT

	TITLE	AUTHORS	SUMMARY
1	**Better Trout Habitat- A Guide to Stream Restoration and Management.**	Hunter. 1995 NOTE: • Studies cited were conducted on small streams.	• A common mistake in bank-stabilization projects is to stabilize eroding banks on the outside of meander bends where the eroding process is natural and creates prime habitat. • If the riparian vegetation is in poor condition, erosion can be greatly accelerated, leading to the loss of land and to collapsed banks that do not provide cover. Often, the response to this situation is to provide structural bank protection in the form of riprap. However this locks the stream into a single, rigid course and limits its ability to create trout habitat. • Boulders have been placed along the margin of the stream where overhanging grasses provide cover. These boulders breakup a long riffle and provide rearing habitat for juvenile trout. • Habitat created by boulders placed along banks in riffles contains juvenile chinook and steelhead while adults have been found to use boulder berms for resting.
2	**Some Effects of Channelization on the Fishes and Invertebrates of Rush Creek, Modoc County, California**	Moyle. 1976 NOTES: • Channelization includes both riprap and channel straightening. • As observed in other studies smaller fish used the channelized section.	• Channelized sections contained fewer and smaller trout as well as a lower biomass than the unchannelized sections. Overall, total fish biomass in the channelized sections was less than one third of that found in the unchannelized sections. • Negative effects on fish and invertebrate populations were noted, but poorly documented. • Average sizes of rainbow trout, brown trout and Modoc sucker were smaller in channelized sections than in unchannelized sections. Pit sculpins and brown trout were more abundant in the channelized sections.

	TITLE	AUTHORS	SUMMARY
			• 80 percent of the biomass in channelized section was rainbow and brown trout. • Studies in Montana show that channelization reduces the average size and number of trout. • Lost carrying capacity was caused by loss of: pools, overhanging bushes, large boulders and other cover habitat components. Only riffle-dwelling fish were able to use the scant cover and turbulent water of the channelized sections.
3	**The Physical and Biological Effects of Physical Alteration on Montana Trout Streams and Their Political Implications. Symposium on Stream Channel Modification.**	Bianchi and Marcoux. 1975	• There were approximately three times as many brown trout in a natural section as compared to a bulldozed section and two times as many as compared to a riprapped section.
4	**Manual of Stream Channelization Impacts on Fish and Wildlife.**	Simpson. 1982 NOTE: • Valuable sections on biological impacts.	Channelization effects are more pronounced for aquatic organisms, and upstream effects are probably greater than downstream effects.
5	**The Place of Channel Improvement in Watershed Development. In-Stream Channelization: A Symposium.**	Martin. 1971	Documented evidence of irreparable damages to fish and wildlife is needed so that mitigation measures and enhancement practices for fish and wildlife can be recognized.

MISSISSIPPI

	TITLE	AUTHORS	SUMMARY
1	**Using Riprap to Create or Improve Riverine Habitat.**	Dardeau. 1995	• Case studies along the Mississippi River illustrate the habitat value of riprap, which is particularly pronounced in alluvial river systems dominated by soft substrates. • Riprap provides hard substrate for invertebrates, which is especially important in alluvial river systems where this material is scarce or absent. • Non-keyed placement of rock can provide direct habitat benefits to fish because such placement of riprap approximates natural situations in which velocity and substrate size are positively associated.
2	**Effects of Channel Restabilization on Habitat Diversity, Twenty Mile Creek, Mississippi**	Shields and Hoover. 1991 NOTES: • Stabilization projects can provide habitat and refuge for some fish species. • (Since this study was done in Mississippi, it has limited application to the Pacific Northwest where conditions are significantly different.) • This study describes the importance of providing diversity in habitat characteristics at bank stabilization projects.	• Grade-control structures (weirs with stone-protected stilling basins) and various types of streambank protection were constructed along the channel in the early 1980s to restore stability. • Grade-control structures also promote biological recovery in unstable, channelized streams by providing coarse, stable substrate. • Three grade-control structures and assorted streambank-protection measures (concrete jacks, stone revetments and combinations of structure, grasses and woody species, primarily Salix spp.) were installed. Grade-control structures consisted of sheet pile or stone weirs with crests above the streambed and approach channels and stilling basins lined with stone riprap and graded stone riprap. • The frequency of eroding banks was greatly reduced due to the presence of riprap revetments. • Diversity was variable among all stations but was higher in Twenty Mile Creek, especially at grade-control structures,

	TITLE	AUTHORS	SUMMARY
			presumably due to higher levels of physical diversity there. • Stream channelization and destabilization reduce aquatic habitat diversity. Although the relationship is complex, stream-fish communities respond positively to increasing levels of habitat diversity. • Grade-control structures and bank-protection structures facilitate habitat recovery in two ways: 1) by promoting overall channel stability, and 2) by serving as major habitat features. • Stabilization structures can provide refuge for fish experiencing reductions in available habitat. Channel-modification projects would be less detrimental to aquatic ecosystems if they were designed and constructed with two-stage cross sections that included low-flow channels. • Species diversity and richness of fish communities in channelized streams are positively associated with structures that increase depth, decrease velocity and increase habitat diversity at low flow.

MIDWEST

	TITLE	AUTHORS	SUMMARY
1	**Stream Channelization in the Midwest. In-Stream Channelization: A Symposium.**	Funk and Ruhr. 1971	• All states have reported that stream-fish habitat has been destroyed and degraded by channelization.
2	**Stream Channelization Effects on Fishes and Bottom Fauna in the Little Sioux River Iowa. In- Stream Channelization: a Symposium.**	Hansen. 1971	• Fish diversity was greater in unchannelized stream section. • A 90-percent reduction was reported in the number of fish per acre per inch length in 23 channelized streams. Forty years following channelization, no significant return to normal stream populations occurred. • Removal of streambank cover was an important factor contributing to higher water temperatures and higher suspended-sediment loads from channel erosion. • Results indicated that channelized sections were not favorable to stable populations of larger game fish.
3	**A Review of References to Channelization and it's Environmental Impact. In-Stream Channelization: A Symposium**	Heneger and Harmon. 1971	• Pounds of fish per acre in the channelized portion of the Blackwater River in Missouri were 131, in the slightly channelized reaches 449 (mostly carp) and in the unchannelized section 565 (primarily channel catfish). • Twenty three channelized streams and 36 natural streams examined by pounds fish per acre in the Lower Piedmont and Coastal Plain of North Carolina were found to be significantly different. Channelization reduced the number of game fish (larger than six inches) per acre by 90 percent, the weight by 85 percent and the standing crop by 80 percent. There was only limited recovery

	TITLE	AUTHORS	SUMMARY
			after 40 years. • The Little Sioux River in Iowa had water temperatures with greater daily fluctuations during the summer in the channelized section. • Consistently higher turbidity levels were found in the channelized portion. • Colonization of macroinvertebrates on artificial substrates suggested lack of suitable attachment areas in the channelized portion. Numbers of fish were fewer in the channelized section. • Flint Creek (Montana), a trout stream, had a 350-foot section dredged, cleared and straightened. This section had been previously inventoried for fish populations for several years. In 1955, a year before the dredging, a total of 20 pounds of fish were taken in this section. Dredging began in 1956 and, in 1957, after the channel "improvements were completed," 1.5 pounds of fish were found in the same section. • Seven times as many fishery-sized trout and over 60 times as many whitefish were collected in natural stream sections in comparison to those that had been subjected to various types of alterations. By weight, the differential was 14 to 1.

FOREIGN SOURCES

	TITLE	AUTHORS	SUMMARY
1	**Effects of River Bed Restructuring on Fish and Benthos of a Fifth Order Stream, Melk, Austria.**	Jungwirth et al. 1993 NOTE: • Recovery after three years is briefly described during the reconditioning of a channelized section of stream by adding groins and bedfalls.	• Benthic drift decreased significantly in the restructured river section, suggesting unfavorable conditions for many benthic invertebrates in the straightened section. Terrestrial invertebrates however, occasionally entering the water body, showed a tenfold increase in drift in the channelized reaches. • The number of fish species observed increased from 10 to 19 and fish density and biomass as well as annual production of 0+ age fish increases threefold. Modeled productions weren't realized, suggesting more time is needed to establish a balanced community.
2	**Effect of Channelization and Regulation of Fish Recruitment in a Floodplain River.**	Jurajda. 1994 NOTES: • This study was conducted on a tributary of the Danube. (It has limited applicability to the Pacific Northwest.) • However, characteristics of the riprap used are similar to that used in the Pacific Northwest – large angular rock, often silted.	• In the absence of areas with lentic backwaters or side arms with aquatic vegetation in the channelized river, the fish could only use the stabilized banks of stony riprap or rare, shallow-slope, gravel shorelines. Shorelines are important as a nursery for all 0+ fishes. Spawning and nursery sites are now limited to the main channel shoreline. • Fish were more influenced by changes in reproduction conditions than by changes in food sources.
3	**Fish of Channelized and Unchannelized Sections of the Bunyip River, Victoria.**	Hortle and Lake. 1983	• The short-term effects of this project (located in Australia) includes a reduction in the numbers and biomass of the resident fish populations of the stream. • The long-term effects of the project depend on whether fish populations can recover by adapting to the new conditions. • The presence of snags (woody debris) is an important determinate of fish abundance. • Channelization reduced trout populations and the lack of suitable physical habitat was the major cause. • Trout were both more abundant and reached a larger size at the unchannelized sites than at the channelized sites.

OTHER REFERENCES:

Ayres Associates. 1996. Sacramento River Bank Protection Project, Sacramento River and tributaries, Lower American River, California: Supplement No. 8a to Design Memorandum No. 2. Prepared for U.S. Army Corps of Engineers Sacramento District, Sacramento, CA.

Jones & Stokes Assoc. 1996. Final Environmental Assessment and initial study of streambank protection at River Park- Lower American River. Prepared for U.S. Army Corps of Engineers, Sacramento District. Sacramento, CA.

Cobb D.G., et al. 1992. Effects of discharge and substrate stability on density and species composition of stream insects. Can. J. Fish. Aquat. Sci (49) 1788-1795.

Faurot, M.W. 1989. Habitat utilization by juvenile pink and chum salmon in Upper Resurrection Bay, Alaska. Final Technical Report EL-89-17. USCOE, Waterways Experiment Station. Vicksburg, MS.

Von Guerard, Paul. 1991. Variation in streambed material, bedload and benthic invertebrates. In: 5th Federal Interagency Sediment Conference. Las Vegas, NV. pg 18-21.

Knight, S.S. and C.M. Cooper. 1991. Effects of bank protection on stream fishes. In: 5th Federal Interagency Sediment Conference. Las Vegas, NV. pg 118-124.

Brittain J.E., et al. 1992. Improvement of fish habitat in a Norwegian River channelization scheme. Regulated rivers: research and management Vol. 8 189-194.

Hynson, J.R., et al. 1985. Environmental features for streamside levee projects. Technical Report E-85-7. USCOE, Waterways Experiment Station. Vicksburg, VA.

Nunnally, N.R. and F.D. Shields Incorporation of environmental features in flood control channel projects. Final Technical Report E-85-3. USCOE, Waterways Experiment Station. Vicksburg, VA.

Marcus, M.D., M.K. Young, L.E. Noel and B.A Mullan. 1988. Salmonid-habitat relationships in the western United States: a review and indexed bibliography. USDA Forest Service, Rocky Mtn Forest and Range Experiment Station. Ft. Collins, CO.

Keown, M.P. 1983. Streambank protection guidelines for landowners and local goverments. USCOE, Waterways Experiment Station. Vicksburg, MS.

McMahon, T.E. 1983. Habitat suitability index models: Coho salmon. U.S. Fish and Wildlife Service, Habitat Evaluation Procedures Group. Report No. FWS/OBS-82/10.49. Ft Collins, CO.

McMahon, T.E. and G.F. Hartman. 1989. Influence of cover complexity and current velocity on winter habitat use by juvenile coho salmon (Oncorhynchus kisutch). Can. J. Fish. Aquat. Sci., Vol. 46 1551-1557.

Groot C. and L. Margolis. 1991. Pacific salmon life histories. Deptartment of Fisheries and Oceans. Pacific Biologicial Station, Nanaimo B.C., Canada. UBC Press. 563pp.

Stern, D.H. and M.S. Stern. 1980. Effects of bank stabilization on the physical and chemical characteristics of streams and small rivers: An annotated bibliography. U.S. Fish and Wildlife Service, Missouri Institute of River Studies. Report No. FWS/OBS-80/12. Rolla, MO.

Duff, D.A. 1988. Indexed bibliography on stream habitat improvement. USDA Forest Service, Intermountain Region, Ogden, UT.

Meehan, W.R. 1991. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society special publication 19. Bethesda, MD.

King County 1993. Guidelines for bank stabilization projects in the rivering environments of King County. Dept. of Public Works, Surface Water Management. Seattle, WA.

Simpson, P.W., et al. 1982. Manual of stream channelization impacts on fish and wildlife. U.S. Fish and Wildlife Service, office of biological services. Report No. FWS/OBS- 82/24. Kearneysville, WV.

U.S. Army Corps of Engineers. 1979. Final Environmental Impact Assessment- Skagit River, Washington. Seattle District, U.S. Army Corps of Engineers. Seattle, WA.

U.S. Army Corps of Engineers. 1989. Environmental engineering for local flood control channels. Engineer manual- EM1110-2-1205. Washington DC.

Washington Dept. of Fisheries. 1984. Draft Special Report - Newaukum River Bank Hardening Projects: Effects on Salmonid Habitat and Recommended Mitigation. Habitat Management Division.

APPENDIX L >>>
<<< APP. TABLE OF CONTENTS
<<< TABLE OF CONTENTS